Claims

1. A method for measuring fluid density comprising the steps of:

Providing a sensor comprising a liquid phase acoustic wave device (LPAWD) having an entrapment layer coupled thereto, the entrapment layer having a textured surface in contact with said fluid, and having a known volume available for entrapping said fluid; the LPAWD comprising an input and an output transducers electromechanically coupled respectively to a first and second resonators, said first and second resonators being sufficiently coupled therebetween to provide said LPAWD with an electrical transfer function characterized by at least a first resonant frequency F_S and a second resonant frequency F_A at or about 180 phase shift relative to said F_s;

feeding an input electrical signal to said input resonator;

measuring the density of the fluid.

2. A method for measuring fluid density according to claim 1 wherein said step of measuring further comprises the steps of:

measuring said second resonant frequency; and,

using said measured resonant frequency, and characteristic response of said LPAWD, calculating the density of the fluid.

3. A method for measuring fluid density according to claim 1, wherein said textured surface covers an approximately equal area of each of said resonators.

4. A method for measuring fluid density according to claim 1 wherein said step of measuring further comprises the step of using a calibration function to account for an approximated viscosity of said fluid.

5. A method for measuring fluid density according to claim 1 further comprising the steps of:

providing an amplifier coupled between said input and output transducers, said amplifier having a gain sufficiently high to cause signals therethrough to oscillate at or about said second resonant frequency F_A; and,

providing a frequency sensing circuit to sense changes in the frequency of oscillations.

6. A method of measuring density and viscosity of a fluid the method comprising the steps of:

providing a sensor comprising a liquid phase acoustic wave device (LPAWD) having an entrapment layer coupled thereto or embedded therein, the entrapment layer having at least one textured surface for contact with said fluid, and having a known volume available for entrapping said fluid; the LPAWD comprising an input and an output transducers electromechanically coupled respectively to a first and second resonators, said first and second resonators being sufficiently coupled therebetween to provide said LPAWD with an electrical transfer function characterized by at least a first resonant frequency F_S, and a second resonant frequency F_A at or about 180 phase shift relative to said F_s;

feeding an input electrical signal to said input transducer;

measuring the density of the fluid; and,

measuring the viscosity of the fluid.

7. A method of measuring density and viscosity according to claim 6, wherein said input electrical signal is controlled to produce a predetermined shear rate under which said viscosity is being measured.

8. A method of measuring density and viscosity according to claim 7, wherein said shear rate is controlled by controlling said input electrical signal at an energy level, P_{IN}, to produce a desired displacement of said entrapment layer.

9. A method of measuring density and viscosity according to claim 8, wherein said energy level, P_{IN}, is calculated so as to obtain the requisite amplitude, U, to provide

the desired shear rate, $\dot{\gamma}$, using the formulae: $U = \delta\dot{\gamma}/\omega$, where $\omega = 2\pi F_A$ is the radian frequency, $\delta = \sqrt{2\eta/\omega\rho}$ is the penetration depth of the wave into a fluid having viscosity, η, and density, ρ, and the acoustic wave amplitude $U = C\sqrt{P_{avg}}$ is determined by a device constant, C, and an energy level, P_{avg}, being a geometric mean of power levels measured at said input P_{IN} and output P_{out} transducers.

10. A method of measuring density and viscosity according to claim 6 further comprising the step of measuring the power difference between the input and output transducers, to obtain a product of the viscosity and density of said fluid.

11. A method of measuring density and viscosity according to claim 6, wherein said step of measuring the density comprises measuring said second resonant frequency, F_A.

12. A method of measuring density and viscosity according to claim 6, wherein said textured surface covers an approximately equal area of each of said resonators.

13. A method of measuring density and viscosity according to claim 6, wherein said step of measuring the viscosity comprises measuring a product of viscosity and density, and further comprises the step of utilizing the measured density and said product.

14. A method of measuring density and viscosity according to claim 6, further comprising the step of using the measured viscosity to compensate for viscosity effects in said step of measuring density.

15. A method of measuring density and viscosity according to claim 6, wherein said step of measuring the density comprises measuring the said second resonant frequency, and wherein said step of measuring the viscosity comprises measuring power insertion loss between said input resonator and output resonator

16. A method of measuring density and viscosity according to claim 6, wherein said step of measuring the viscosity comprises measuring the shift of one or both of said resonant frequencies.

17. A method of measuring density and viscosity according to claim 6, further comprising the step of controlling the energy level of said input electrical signal so as to control the shear rate in which said viscosity is measured;

Wherein said step of measuring density comprises measuring the frequency shift of said second resonant frequencies; and,

Wherein said step of measuring the viscosity comprises measuring the power insertion loss between said first and second resonator.

18. **A sensor** for measuring viscosity and density of a fluid, the sensor comprising:

a substrate having an input and an output transducer, coupled respectively to a first and a second resonators;

said first and second resonators being sufficiently closely coupled therebetween to form an electrical transfer function characterized by at least a first resonant frequency F_S, and a second resonant frequency F_A at or about 180 phase shift relative to said frequency F_s; and,

an entrapment layer coupled to said substrate, or embedded therein.

19. A sensor for measuring viscosity and density of a fluid as claimed in claim 18, wherein said entrapment layer is coupled to said substrate by an intermediate layer.

20. A sensor for measuring viscosity and density of a fluid as claimed in claim 18, wherein said entrapment layer comprises at least one face having grooves formed thereupon, for trapping a known volume of said fluid.

21. A sensor for measuring viscosity and density of a fluid as claimed in claim 20, wherein said grooves are formed by depositing material on said face to form ridges, the grooves being defined between said ridges.

22. A sensor for measuring viscosity and density of a fluid as claimed in claim 20, wherein said grooves are oriented perpendicular to the direction of wave motion in said substrate.

23. A sensor for measuring viscosity and density of a fluid as claimed in claim 20, wherein said grooves are dimensioned to be smaller than the length of a quarter of the wavelengths in the liquid, of said resonant frequency F_S.

24. A sensor for measuring viscosity and density of a fluid as claimed in claim 18, wherein said entrapment layer comprises at least one chamber formed therein, said chamber having at least one opening for entrapping a known volume of said fluid.

25. A sensor for measuring viscosity and density of a fluid as claimed in claim 24, wherein said chamber is cut into a face of said entrapment layer.

26. A sensor for measuring viscosity and density of a fluid as claimed in claim 24, wherein said chamber is formed by material deposited onto said entrapment layer.

27. A sensor for measuring viscosity and density of a fluid as claimed in claim 18, wherein said entrapment layer is integral to at least one face of said substrate.

28. A sensor for measuring viscosity and density of a fluid as claimed in claim 18, wherein said entrapment layer comprises a textured surface for entrapment of a known volume of said fluid.

29. A sensor for measuring viscosity and density of a fluid as claimed in claim 18, wherein said entrapment layer covers an approximately equal area of each of said resonators.

30. A sensor for measuring viscosity and density of a fluid as claimed in claim 18, wherein said entrapment layer covers at least 50% of frontal area of each said resonators.

31. A sensor for measuring viscosity and density of a fluid as claimed in claim 18, wherein said entrapment layer comprises an area having a plurality of cavities.

32. A sensor for measuring viscosity and density of a fluid as claimed in claim 31, wherein said area cover substantially a whole surface of at least one face of said entrapment layer.

33. A sensor for measuring density of a fluid, the sensor comprising:

a substrate having an input and an output transducers, coupled respectively to a first and a second resonators, said resonators embedded within said substrate;

said input resonator and output resonator being sufficiently closely coupled therebetween to form an electrical transfer function characterized by at least a first resonant frequency F_S, and a second resonant frequency F_A, F_S and a second resonant frequency F_A at or about 180 degrees phase to said frequency F_S; and,

an entrapment layer coupled to said substrate, or embedded therein.

34. A sensor for measuring density of a fluid as claimed in claim 33, wherein said entrapment layer is coupled to said substrate by an intermediate material.

35. A sensor for measuring density of a fluid as claimed in claim 33, wherein said entrapment layer comprises at least one face having grooves formed thereupon, for trapping a known volume of said fluid.

36. A sensor for measuring density of a fluid as claimed in claim 35, wherein said grooves are formed by depositing material on said face to form ridges, the grooves being defined between said ridges.

37. A sensor for measuring density of a fluid as claimed in claim 35, wherein said grooves are oriented perpendicular to the direction of wave motion in said substrate.

38. A sensor for measuring density of a fluid as claimed in claim 35, wherein said grooves are dimensioned to be smaller than the length of one quarter of a wavelength in the liquid, of said resonant frequency F_S.

39. A sensor for measuring density of a fluid as claimed in claim 33, wherein said entrapment layer comprises at least one chamber formed therein, said chamber having at least one opening for entrapping a known volume of said fluid.

40. A sensor for measuring density of a fluid as claimed in claim 39, wherein said chamber is cut into a face of said entrapment layer.

41. A sensor for measuring density of a fluid as claimed in claim 39, wherein said chamber is formed by material deposited onto said entrapment layer.

42. A sensor for measuring density of a fluid as claimed in claim 33, wherein said entrapment layer is integral to at least one face of said substrate.

43. A sensor for measuring density of a fluid as claimed in claim 33, wherein said entrapment layer is textured for entrapping a known volume of said fluid.

44. A sensor for measuring density of a fluid as claimed in claim 33, wherein said entrapment layer comprises at least one groove.

45. A sensor for measuring viscosity and density of a fluid as claimed in claim 18, wherein said entrapment layer covers an approximately equal area of each of said resonators.

46. A sensor for measuring density of a fluid as claimed in claim 33, wherein said entrapment layer covers at least 50% of frontal area of each said resonators.

47. A sensor for measuring density of a fluid as claimed in claim 33, wherein said entrapment layer comprises an area having a plurality of cavities.

48. A sensor for measuring density of a fluid as claimed in claim 47, wherein said area cover substantially a whole surface at least one face of said entrapment layer.

49. **An apparatus** for measuring density and viscosity of a fluid, the apparatus comprising:

a sensor comprising:

a substrate having an input and an output transducers coupled respectively to a first and a second resonators;

said first and second resonators being sufficiently closely coupled therebetween to form an electrical transfer function characterized by at least a first resonant frequency F_S, and a second resonant frequency F_A, at or about 180 degrees phase shift to said frequency F_S;

an entrapment layer coupled to said substrate, or embedded therein;

a first measuring means for measuring the density of said fluid; and,

a second measuring means for measuring a product of said viscosity and density.

50. An apparatus for measuring density and viscosity of fluid in accordance with claim 49, further comprising a computer adapted for computing the density from the measured product and the measured density.

51. An apparatus for measuring density and viscosity of fluid in accordance with claim 49, wherein said first measuring means comprise frequency measurement equipment.

52. An apparatus for measuring density and viscosity of fluid in accordance with claim 49, wherein said first measuring means comprises:

A first oscillator coupled between said input and resonator, constructed to oscillate at 180° phase relative to an input electrical energy inputted to said input transducer; and,

A second oscillator coupled between said output and input resonator and constructed to oscillate at or about 0° phase from said input electrical energy.

53. An apparatus for measuring density and viscosity of fluid in accordance with claim 49, wherein said second measuring means comprises circuitry to measure insertion power loss between said input and output transducers.

54. An apparatus for measuring density and viscosity of fluid in accordance with claim 49, wherein said second measuring means comprises circuitry to measure difference frequencies between said first and second oscillators.

55. An apparatus for measuring density and viscosity of fluid in accordance with claim 49, wherein said entrapment layer comprises a groove.

56. An apparatus for measuring density and viscosity of fluid in accordance with claim 49, wherein said entrapment layer comprises a plurality of grooves.

57. An apparatus for measuring density and viscosity of fluid in accordance with claim 56, further comprising a plurality of ridges deposited upon at least one face of said entrapment layer, said grooves being defined between said ridges.

58. An apparatus for measuring density and viscosity of fluid in accordance with claim 56, wherein said plurality of grooves are etched into at least one face of said entrapment layer.

59. An apparatus for measuring density and viscosity of fluid in accordance with claim 49, wherein said entrapment layer comprises at least one face of said substrate.

60. An apparatus for measuring density and viscosity of fluid in accordance with claim 49, wherein said entrapment layer is coupled to said substrate by intermediate material.

61. An apparatus for measuring density and viscosity of fluid in accordance with claim 49, wherein said entrapment layer comprises at least one chamber.

62. An apparatus for measuring density and viscosity of fluid in accordance with claim 49, wherein the level of input energy applied to said input transducer is controlled.

63. An apparatus for measuring density and viscosity of fluid in accordance with claim 62, wherein said input energy is controlled to provide a known displacement of at least one face of said substrate.

64. An apparatus for measuring density and viscosity of fluid in accordance with claim 62, wherein said input energy is controlled to measure the viscosity of the fluid at varying shear rates.

65. An apparatus for measuring density and viscosity of fluid in accordance with claim 57, further comprising a temperature sensor for measuring the temperature of said fluid.